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AUTOMATED STRUCTURAL OPTIMIZATION SYSTEM (ASTROS) DAMAGE TOLERANCE MODULE

VOLUME III -- INTERFACE DESIGN DOCUMENT

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FINAL REPORT FOR 09/30/1996 – 09/30/1998

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13. ABSTRACT *(Maximum 200 words)*

This report was developed under SBIR contract.

This report is part of the documentation that describes the complete development of an SBIR Phase II effort titled, "An ASTROS Compatible Computational Strategy for Evaluating the Aeroelastic Response, Buckling, and Integrity of Composite A/C". This report is one of three manuals that comprise the final documentation. The remaining reports consist of a Final Report, Volume I, and a User's Manual, Volume II..

The Automated STRuctural Optimization System (ASTROS) is a multidisciplinary computer program for the preliminary design of aircraft and spacecraft structures. It integrates structures, aerodynamics, controls and optimization to make possible interdisciplinary design.

This report describes the user input necessary to exercise the damage tolerance module. In addition to standard ASTROS input data cards for the description of the preliminary design model, the user has to specify the following information to analyze discrete source damage: the master element, the layout and properties of the panel, the damage, and the analysis control parameters using bulk data cards. A detailed description of the bulk data cards introduced by the damage tolerance module is discussed and a brief summary with examples is also given.

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FOREWORD

This is the final report on the work performed by Knowledge Systems, Inc. on the U.S. Air Force Contract F33615-96-C-3215, "An ASTROS Compatible Strategy for Evaluating the Aeroelastic Response, Buckling and Integrity of Composite A/C". This report contains 3 parts: 1) "ASTROS Damage Tolerance Module: Final Report"; 2) "ASTROS Damage Tolerance Module: Interface Design Document"; and 3) "ASTROS Damage Tolerance Module: User's Manual".

This report details the work performed to enhance the capability of ASTROS to perform preliminary design optimization of metallic and composite material aircraft, based on damage tolerance requirements. The customized damage tolerance models that have been implemented in ASTROS, at present, are:

1. Discrete Source Damage Model: A lead crack in a stiffened panel with/without the presence of a central broken stiffener;
2. BuckDel model: Buckling of a composite panel in the presence of a delamination;
3. Straight Crack Model: A panel with a central crack;
4. Rivet Hole Crack Model: One (or two) crack(s) emanating from one side (or both sides) of a rivet hole;
5. Curved Crack Model: A panel with a curved crack;
6. Rivet Hole Curved Crack Model: One (or two) curved crack(s) emanating from one side (or both sides) of a rivet hole;
7. Surface Crack Model: One centered surface crack in a plate;
8. Rivet Hole Corner Crack Model: Two corner cracks emanating from both the sides of a straight-shank rivet hole.

The authors acknowledge the contributions of D.S. Pipkins, P.E. O' Donoghue, K. O' Sullivan, and H. Kawai to various parts of this report.

It is a pleasure to acknowledge the constant support, constructive criticism, and valuable insights, provided by Drs. V.A. Tischler and V.B. Venkayya of AFRL during the course of this project.

CHAPTER I

INTRODUCTION

The Automated STRuctural Optimization System (ASTROS) is an extendible system built on the top of an engineering database and the Matrix Analysis Problem Oriented Language (MAPOL). The database provides a channel for the inter-module communication in ASTROS; while MAPOL provides extendability to ASTROS. During the integration of the damage tolerance module into ASTROS, an extremely powerful "gluing tool" – Tool Command Language (TCL) is introduced into ASTROS.

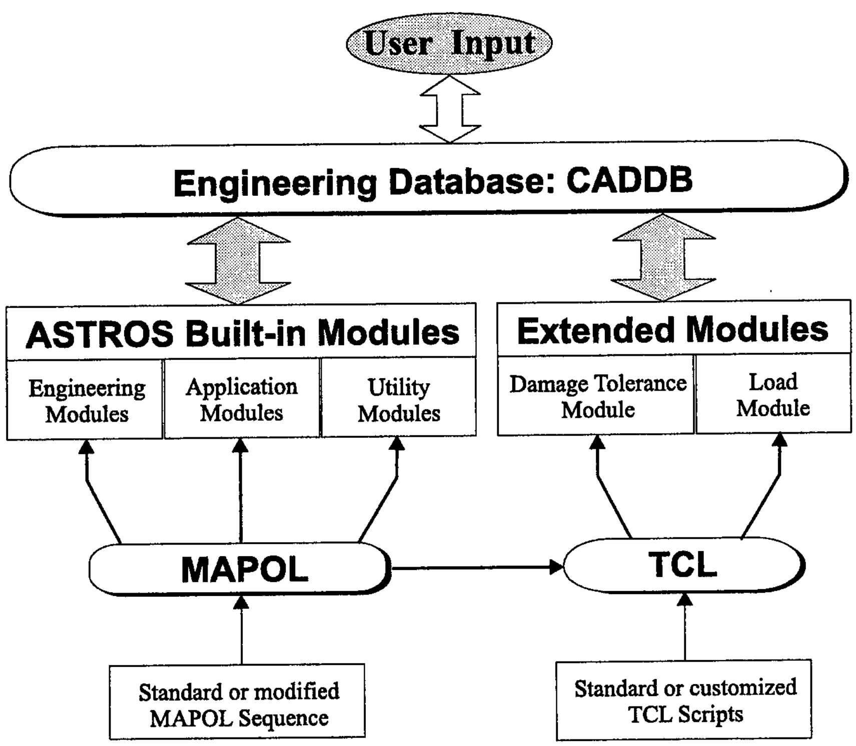

Figure 1.1: Integration of damage tolerance module with ASTROS

The damage tolerance module is a complex system by itself. It includes customized mesh generators, finite element alternating [Schwartz-Neumann Alternating] codes (for 2D straight cracks, 2D curved cracks and 3D elliptical/circular cracks), an automated Global/Local analyzer, and a buckling analyzer. They were developed using different computer languages, such as C, C++ and FORTRAN. In order to integrate the damage tolerance module into ASTROS, a TCL interpreter is planted into ASTROS as a module invokable from the MAPOL sequence.

Fig. 1.1 shows the interfacing strategy for incorperating damage tolerance into ASTROS. It is seen in Fig. 1.1 that the Damage Tolerance Module communicates with other Built-in Modules of ASTROS through the Engineering Database. The extended modules are controlled by TCL scripts, which are interpreted by the embedded TCL interpreter. The interpreter is in turn controled by the modified MAPOL sequence.

Interfacing aspects, related to MAPOL, DATABASE and TCL, are documented in this chapter. Database entities used by the damage tolerance module to communicate with other modules are described in the next chapter.

1.1 MAPOL

As seen in Fig. 1.1, the MAPOL sequence does not control the damage tolerance module directly. It interacts with the TCL module only.

A single argument (`INTEGER`) is passed to the TCL module from the MAPOL calling sequence. This argument indicates the position in the MAPOL sequence, from which the MAPOL call is placed. This status indicator is set as the value of the global TCL variable `astrosStateID`. Depending on the value of `astrosStateID`, the TCL module i) creates an interpreter; ii) performs input data check; iii) performs damage tolerance analysis; or iv) deletes the interpreter, etc. No other direct data communication is made between the MAPOL calling sequence and damage tolerance module. The damage tolerance module communicates with the rest of the modules in ASTROS, though the database entities, to get the data required for damage tolerance analyses. It also stores the results in the database for other modules to access.

MAPOL calling sequence for the TCL module is the following

```
CALL TCL(N)
```

where `N` is an integer parameter. Current designations are described as follows.

`N`	**Description**
`1`	Create the main TCL interpreter
`0`	Delete the main TCL interpreter
`10`	Start-up actions before calling other modules
`11`	Additional data checking after the module `IFP`
`14`	Damage tolerance analysis
`15`	Clean-up actions before exiting the MAPOL calling sequence

1.2 DATABASE

ASTROS relies on the engineering database for inter-module communication. Originally based on the Computer Automated Design Database (CADDB), which was the heart of ASTROS during its development, the commercially supported ASTROS is now based on the eBASE database developed by UAI. In this project, the set of interface routines for CADDB are used to access database entries. To facilitate the migration from CADDB to eBASE, the damage tolerance module uses a set of TCL commands to access the database via the CADDB interface. To migrate from the CADDB interface to the eBASE interface, it will be necessary to re-implement only these TCL commands using the eBASE access routines.

1.3 TCL

Tool Command Language (TCL) is a simple, yet robust scripting language. It is an excellent scripting language for extending the functionality of existing programs. TCL was originally developed at the University of California, Berkeley. The development was later shifted to Sun Microsystems, Inc. Currently, it is commercially supported by Scriptics, Inc. The core system of TCL is freely distributed with the source code. Although it is distributed without a charge, it is very stable and of commercial quality. TCL has become an increasingly popular cross-platform scripting language. Many commercial software have been developed based on TCL.

TCL consists of a scripting language and an interpreter for that language. The TCL interpreter is designed such that it can be easily embedded into other applications. As a language, it is much like the UNIX shell language. There is very little syntax; and it is very easy to learn. TCL has been used to assemble software modules that have been built in system programming languages like C, C++ and FORTRAN. These building blocks appear as commands, or verbs, in TCL.

Online user manuals are available at Scriptics' web site (`http://www.scriptics.com/man/tcl8.0/contents.htm`). Much more helpful information can be found at `http://www.scriptics.com/resource/`.

The damage tolerance module is actually a complex system. It includes customized mesh generators, finite element alternating codes [based on the Schwartz-Neumann alternating method](for 2D straight cracks, 2D curved cracks and 3D elliptical/circular cracks), an automated Global/Local analyzer, and a buckling analyzer. They were developed using different computer languages, such as C, C++ and FORTRAN. In order to integrate the damage tolerance module into ASTROS, a TCL interpreter is planted into ASTROS as a module invokable from the MAPOL sequence. The MAPOL calling sequence is described in § 1.1.

CHAPTER II

SCHEMATA DESCRIPTION

The database is designed to be the main interface for inter-module communication in ASTROS. The Damage Tolerance module (DT module) makes use of this interface to communicate with other modules in ASTROS. In addition to using the data entities defined in the standard ASTROS distribution, the Damage Tolerance module introduces an additional set of data entities.

The DT module needs data entries for the definitions of the damages (i.e. cracks, delaminations, holes, etc.) When ASTROS is re-generated using the system generation program `SYSGEN`, new bulkdata cards are added into the system. The Input File Processor (IFP) module can then process the input data cards for the definitions of the damages. The DT module uses these input data entries, along with the standard database entities created by various modules in ASTROS, to perform a damage tolerance analysis. The results for the damage tolerance analysis are stored in the database. The schemata for the database entities are described in this chapter. In this document, the reader is assumed to be familiar with the database used in ASTROS, which is documented in detail in the *Theoretical Manual* and *Programmer's Manual* for ASTROS.

A summary of the entities introduced by the DT module is presented as follows.

CATEGORY	ENTITIES
Flight life definition	FLTSEQ, FLT, FLTBLK, FLTMSN, FLTSGT, FLTSPC
Damage definition	DTWC, DHLTWC, DSF, DHLSF, DCVC, DHLCVC, DDSD, DBKDEL, CVPATH
Panel definition	PNLELM, PNLSTF
Control Parameters	DTCNTL, CFTG, CTWC, CHLTWC, CSF, CHLSF, CCVC, CHLCVC, CDSD, CBKDEL
Fracture Properties	FRACMT
Analysis Results	PDTWC, PDHLTWC, PDSF, PDHLSF, GELP, SIF

Entity: DTWC

Entity Type: Relation

Description: Defines the dimensions of a through wall crack

Relation Attributes:

NAME	TYPE	DESCRIPTION
DMG	KI>0	Crack ID (DTWC)
A	R>0	The half length (a) of the crack

Created By: Module IFP

Remarks:

1. The beta factors for mode I and mode II SIFs are defined as:

$$\beta_1 = \frac{K_I}{\sigma_y\sqrt{\pi a}}, \qquad \beta_2 = \frac{K_{II}}{\sigma_{xy}\sqrt{\pi a}}$$

   where σ_y and σ_{xy} are the normal and shear stresses in the master element in the crack coordinate system.

2. Both crack tips are assumed to have the same SIFs.

3. The crack tip ID for the left crack is 1.

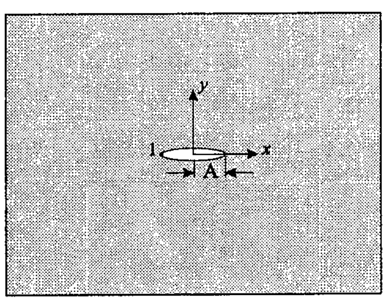

Figure 2.1: A through wall crack

Entity: `DHLTWC`

Entity Type: Relation

Description: Defines the dimensions of the cracks emanating from a rivet hole

Relation Attributes:

NAME	TYPE	DESCRIPTION
DMG	KI>0	Crack ID
A1	R>=0	The length (a_1) for the crack to the left of the rivet hole
A2	R>=0	The length (a_2) for the crack to the right of the rivet hole
RADIUS	R>0	The radius (r) of the rivet hole

Created By: `Module IFP`

Remarks:

1. The beta factors for mode I and mode II SIFs are defined as:

$$\beta_1 = \frac{K_I}{\sigma_y\sqrt{\pi a}}, \qquad \beta_2 = \frac{K_{II}}{\sigma_{xy}\sqrt{\pi a}}$$

   where σ_y and σ_{xy} are the normal and shear stresses in the master element in the crack coordinate system; $a = r + (a_1 + a_2)/2$.

2. The crack tip ID for the crack `A1` is 1.

3. The crack tip ID for the crack `A2` is 2.

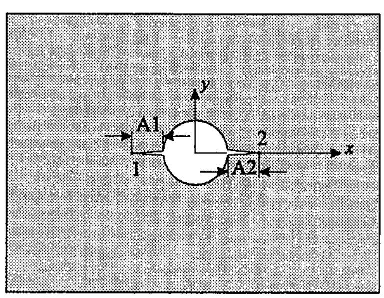

Figure 2.2: Two cracks emanating from a hole

Entity: DSF

Entity Type: Relation

Description: Defines the dimensions of a semi-elliptical/circular surface flaw

Relation Attributes:

NAME	TYPE	DESCRIPTION
DMG	KI>0	Crack ID
A	R>0	Half Length (a) of the crack
B	R>0	Depth (b) of crack

Created By: `Module IFP`

Remarks:

1. The beta factors for mode I and mode II SIFs are defined as:

$$\beta_1 = \frac{K_I}{\sigma_y\sqrt{\pi\bar{a}}}, \qquad \beta_2 = \frac{K_{II}}{\sigma_{xy}\sqrt{\pi\bar{a}}}, \qquad \beta_3 = \frac{K_{III}}{\sigma_{xy}\sqrt{\pi\bar{a}}}$$

   where σ_y and σ_{xy} are the normal and shear stresses in the master element in the crack coordinate system; $\bar{a} = \min(a, b)$.

2. The crack tip ID for the points on the crack front are shown in the Fig. 2.3

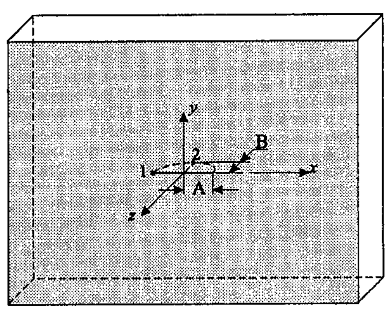

Figure 2.3: A surface flaw of the shape of semi-ellipse/circle

Entity: DHLSF

Entity Type: Relation

Description: Defines the dimensions of corner cracks emanating from a rivet hole

Relation Attributes:

NAME	TYPE	DESCRIPTION
DMG	KI>0	Crack ID
A	R>0	Length (a) of the crack
B	R>0	Depth (b) of the crack
RADIUS	R>0	The radius (r) of the rivet hole

Created By: Module IFP

Remarks:

1. Two corner cracks ementating from both sides of the hole. They are symmetric about the y-axis.

2. The beta factors for mode I and mode II SIFs are defined as:

$$\beta_1 = \frac{K_I}{\sigma_y\sqrt{\pi\bar{a}}}, \qquad \beta_2 = \frac{K_{II}}{\sigma_{xy}\sqrt{\pi\bar{a}}}, \qquad \beta_3 = \frac{K_{III}}{\sigma_{xy}\sqrt{\pi\bar{a}}}$$

   where σ_y and σ_{xy} are the normal and shear stresses in the master element in the crack coordinate system; $\bar{a} = \min(a,b)$.

3. The crack tip ID for the points on the crack front are shown in the Fig. 2.4

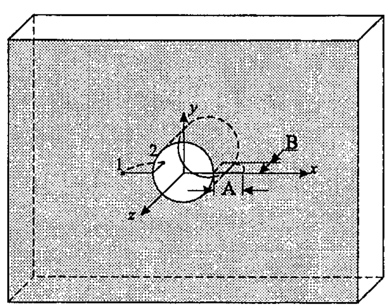

Figure 2.4: Two corner cracks emanating from a hole

Entity: DCVC

Entity Type: Relation

Description: Defines the dimensions of a curved crack

Relation Attributes:

NAME	TYPE	DESCRIPTION
DMG	KI>0	Crack ID
PATH	I>0	Path ID (CVPATH)

Created By: Module IFP

Remarks:

1. The beta factors for mode I and mode II SIFs are defined as:

$$\beta_1 = \frac{K_I}{\sigma_y\sqrt{\pi a}}, \qquad \beta_2 = \frac{K_{II}}{\sigma_{xy}\sqrt{\pi a}}$$

   where σ_y and σ_{xy} are the normal and shear stresses in the master element in the coordinate system for the equivalent crack. The equivalent crack is defined by the straight line connecting the two crack tips of the curved crack. a is the half length of the equivalent crack.

2. The crack tip ID for the first crack tip (corresponding to the first point in PATH) is 1; and the crack tip ID for the second crack tip (corresponding to the last point in PATH) is 2.

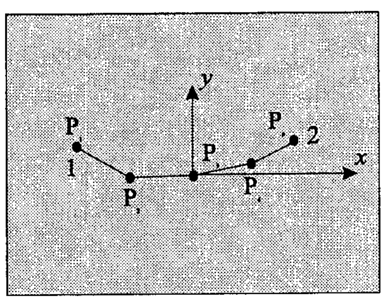

Figure 2.5: A curved crack

Entity: DHLCVC

Entity Type: Relation

Description: Defines the dimensions of the curved cracks emanating from a rivet hole

Relation Attributes:

NAME	TYPE	DESCRIPTION
DMG	KI>0	Crack ID
PATH1	I>=0	Path ID (CVPATH) for the first crack
PATH2	I>=0	Path ID (CVPATH) for the second crack
RADIUS	R>0	The radius (r) of the rivet hole

Created By: `Module IFP`

Remarks:

1. The beta factors for mode I and mode II SIFs are defined as:

$$\beta_1 = \frac{K_I}{\sigma_y \sqrt{\pi a}}, \qquad \beta_2 = \frac{K_{II}}{\sigma_{xy} \sqrt{\pi a}}$$

   where σ_y and σ_{xy} are the normal and shear stresses in the master element in the coordinate system for the equivalent crack. The equivalent crack is defined by the straight line connecting the two crack tips of the curved crack. a is the half length of the equivalent crack.

2. The crack tip ID for the first crack tip is 1; and the crack tip ID for the second crack tip is 2.

3. Both crack paths mush be defined such that the last points are the crack tips.

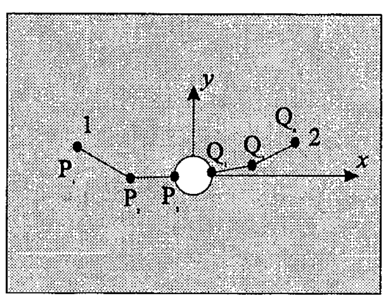

Figure 2.6: The curved cracks emanating from a rivet hole

Entity: DDSD

Entity Type: Relation

Description: This data entry describes the characteristics of the single lead crack as discrete source damage. The crack is placed at the center bay of the panel, either horizontally or vertically. The stiffeners which intersect with the crack may or may not be broken.

Relation Attributes:

NAME	TYPE	DESCRIPTION
DMG	KI>0	This field represents the data entry ID of this data entry
VRTCL	C(8)	Defines the orientation of the crack
INTACT	C(8)	Describes whether the stiffeners or frames are intact or broken by the crack

Created By: `Module IFP`

Remarks:

1. VRTCL, this field represents whether the crack orientation is vertical or horizontal.

   To analyze with the user defined settings, enter 'YES'. This will define the crack as vertical, i.e., the crack is parallel with the frames. If the panel is curved, the crack is known as the circumferential crack.

   To analyze with the default settings, leave value as 'NO'. This will define the crack as horizontal, i.e., the crack is parallel with the stringers. If the panel is curved, the crack is known as the longitudinal crack.

2. INTACT. This field represents whether the stiffeners are intact or broken by the crack

   To analyze with the user defined settings, enter 'YES'. This will define the stiffeners or the frames to be broken. In the case of a vertical crack, the stiffeners which will intersect with the crack will be broken. In the case of a horizontal crack, the frames which will intersect with the crack will be broken.

   To analyze with the default settings, leave value as 'NO'. This will define both the stiffeners and the frames to be intact with the skin sheet.

Entity: DBKDEL

Entity Type: Relation

Description: This data entry describes the damage due to delamination. The delaminate region can be placed at the center bay of the panel. The shape of the delaminate region is an ellipse. This information is represented by diameters of two axis. Information about the composite laminate is also specified.

Relation Attributes:

NAME	TYPE	DESCRIPTION
DMG	KI>0	This field represents the data entry ID of this data entry
WIDTH	R>0	Width of the delaminate region
LENGTH	R>0	Length of the delaminate region
PLT	R>0	Thickness of a ply
NPLDL	I>=0	Number of plies of the delaminate region
NPLBS	I>0	Number of plies of the base region

Created By: `Module IFP`

Remarks:

1. `WIDTH` represents the width of the delaminate region in the horizontal direction. The delaminate region is an ellipse, and the width is the diameter of the ellipse along the horizontal axis.

   To analyze with the user defined settings, enter a value greater than zero. This value defines the width of the delaminate in the horizontal direction.

2. `LENGTH` represents the length of the delaminate region in the vertical direction. The delaminate region is an ellipse, and the length is the diameter of the ellipse along the vertical axis.

   To analyze with the user defined settings, enter a value greater than zero. This value defines the length of the delamination in the vertical direction.

3. `NPLDL` represents the number of plys of the delaminate region.

   To analyze with the user defined settings, enter a value greater than zero. The panel has the delaminate region, and this value will define the number of plys of the delaminate region. The number of plys of the undelaminate region is the sum of `NPLBS` and `NPLDL`.

   To analyze with the default settings, leave the value as zero. The panel does not have a delaminate region.

4. NPLBS represents the number of plys of the base region.

   To analyze with the user defined settings, enter a value greater than zero. This value will define the number of plys of the base region. If NPLDL is zero, then the panel does not have delaminate region, and this value will define the number of plys of the undelaminated region. Otherwise, the number of plys of the undelaminate region is the sum of NPLBS and NPLDL.

Entity: CVPATH

Entity Type: Relation

Description: Defines the cracking path of a curved crack

Relation Attributes:

NAME	TYPE	**DESCRIPTION**
CVPATH	I>0	Path ID
X	R	The x-coordinates (x_n) of the points on the path in the crack coordinate system
Y	R	The y-coordinates (y_n) of the points on the path in the crack coordinate system

Created By: `Module IFP`

Remarks:

1. Points on the path must be defined in the sequence according to their position on the path.
2. The crack tip must be the last point for the path that has only one crack tip.

Entity: FLTSEQ

Entity Type: Relation

Description: Defines the load history a structure is subjected to over its life (often called the design usage) in terms of a series of flights

Relation Attributes:

NAME	TYPE	DESCRIPTION
FLTSEQ	I>0	Flight Sequence ID
FLT	I>0	Flight ID
REPEAT	I>0	Number of times

Created By: Module IFP

Remarks:

1. A series of flights, sharing the same FLTSEQ ID, defines one design life of an aircraft.
2. The series of flights should be repeated whenever possible to reduce the system requirements (file space) necessary to store the load history data.

Entity: FLT

Entity Type: Relation

Description: Describes the load history of a Flight in terms of a series of mission blocks

Relation Attributes:

NAME	TYPE	DESCRIPTION
FLT	I>0	Flight ID
FLTBLK	I>0	Block ID
REPEAT	I>0	Number of times

Created By: Module IFP

Remarks:

1. A series of mission blocks, sharing the same FLT ID, defines a flight.
2. When defining the design of an aircraft, a Flight typically consists of 500 or 1000 flight hours. The actual time duration each Flight represents is determined from the build up of Mission Segments, Missions, and Mission Blocks as specified by the user.

Entity: FLTBLK

Entity Type: Relation

Description: Defines a mission block in terms of a series of Missions with a duration

Relation Attributes:

NAME	TYPE	DESCRIPTION
FLTBLK	I>0	Block ID
FLTMSN	I>0	Mission ID
REPEAT	I>0	Number of times

Created By: Module IFP

Remarks:

1. A series of missions, sharing the same FLTMSN ID, defines a flight block.

Entity: FLTMSN

Entity Type: Relation

Description: Defines the load history in terms of a series of Mission Segments with a specified duration

Relation Attributes:

NAME	TYPE	DESCRIPTION
FLTMSN	I>0	Mission ID
FLTSGT	I>0	Flight Segment ID
TIME	R>0	Flight time for this mission segment

Created By: Module IFP

Remarks:

1. A series of mission segments, sharing the same FLTMSN ID, defines a mission.

Entity: FLTSGT

Entity Type: Relation

Description: Defines the load history of a Mission Segment when there is only one load case (maneouver) in each level of the Mission Segment Load Spectrum

Relation Attributes:

NAME	TYPE	DESCRIPTION
FLTSGT	KI>0	Segment ID
FLTSPC	I>0	Spectrum ID
OCCEXC	C(8)	Occurance or Exceedance
PERIOD	R>0	The flight time on which the spectrum is based

Created By: Module IFP

Remarks:

1. OCCEXC indicates whether FLTSPC is an occurance spectrum or an excedence spectrum.
2. The occrurance/excedence numbers in the spectrum FLTSPC are based on the flight time PERIOD.

Entity: FLTSPC

Entity Type: Relation

Description: Defines the flight specturm in terms of a collection of loading ASTROS loading cases

Relation Attributes:

NAME	TYPE	DESCRIPTION
FLTSPC	I>0	Spectrum ID
NUMTIM	R>0	Number of occurance/exceedence
CASEID	I>0	ASTROS CASEID
SCALE	R	Scaling factor for the loading condition

Created By: Module IFP

Remarks:

1. Number of occurance/exceedence is based on the PERIOD defined in FLTSGT.

Entity: PNLELM

Entity Type: Relation

Description: This data entry describes the master element of the panel. The master element is one of the shell elements in the global model. This element contains the panel described in the PNLSTF data entry and also contains information for the intermediate and/or the local model. The boundary conditions of the intermediate or the local model are obtained from the analysis results on this element. If there is any information missing from the panel's data entries, the program will automatically derive this missing information from the master element.

Relation Attributes:

NAME	TYPE	DESCRIPTION
ID	KI>0	This field represents the data entry ID of this data entry
ETYPE	C(8)	The type of the master element. (CHARACTER) Currently available choices: QUAD4, TRIA3.
EID	I>0	The element ID of the master element

Created By: Module IFP

Remarks:

1. None.

Entity: PNLSTF

Entity Type: Relation

Description: This data entry describes the skin sheet and the stiffeners of the panel. The stiffener information is relevant to the discrete source damage problem only. The panel is referred from the master element. The master element is one of the shell elements in the global model, and it contains the entire panel. In the dicrete source damage problems, this data entry represents the skin sheet and the stiffeners information of the intermeidate and the local model. In the other problems, it represents the skin sheet information of the local model.

Relation Attributes:

NAME	TYPE	DESCRIPTION
PNLSTF	KI>0	This field represents the data entry ID of this data entry
MAT	R>=0	Material property ID of the skin sheet of the panel
SKIN	R>=0	Thickness of the panel's skin
WIDTH	R>=0	Width of the panel
LENGTH	R>=0	Length of the panel
RADIUS	R>=0	Radius of the panel
BARSTR	I>=0	Bar geometrical property ID of the stringers of the panel
BARFRM	I>=0	Bar geometrical property ID of the frames of the panel
STRPSCH	R>0	Rivet pitch along the stringers of the panel
STRSPC	R>=0	Stringer spacing of the panel
FRMPCH	R>0	Rivet pitch along the frames of the panel
FRMSPC	R>=0	Frame spacing of the panel

Created By: Module IFP

Remarks:

1. In the case of discrete source damage problems, the following criteria is applied:
   The intermediate model covers the entire panel. The boundary conditions of the intermediate model are developed from the global analysis of the master element. The local model is a portion of the intermediate model.
   The panel can be flat or curved. If curved, the panel is regarded as cylindrical, the horizontal direction of the panel becomes the longitudinal direction, while the vertical direction becomes the circumferential direction.

The horizontal stiffeners are the stringers, and the vertical stiffeners are the frames.

Horizontal crack: The number of stringer bays must be odd and the number of frame bays must be even. The horizontal crack must be placed between two stringers, and it must cross the central frame, which can be broken.

Vertical crack: The number of frames bays must be an odd number and the number of stringer bays must be an even number. The vertical crack must be placed between two frames, and it must cross with the center stringer, which can be broken.

In the other problems, only skin sheet data are relevant. The data are used for the local model.

2. MAT: This field represents the material property ID of the panel's skin sheet.

   To analyze with the user defined settings, enter a value greater than zero. In the case of buckling and delamination problems, the selected MAT1 or MAT8 data entry will be used for the material properties of the ply of the skin sheet as a composite lamina. In the other problems, the selected MAT1 data entry will be used for the skin sheet.

   To analyze with the default settings, the leave value as zero. The skin sheet's material properties will be obtained from the master element.

3. SKIN: This field represents the thickness of the panel's skin sheet.

   To analyze with the user defined settings, enter a value greater than zero. In the case of buckling and delamination problems, this field value is ignored, and the value in the DBKDEL data entry is used instead of it. In the other problems, this field value will define the thickness of the skin sheet.

   To analyze with the default settings, leave the value as zero. The skin sheet's thickness will be obtained from the master element.

4. WIDTH: This field represents the width of the panel.

   To analyze with the user defined settings, enter a value greater than zero. In the case of discrete source damage problems, this field value will define the width of the panel at the intermediate stage. If the total distance between the two end frames is greater than the entered value, the width will automatically adjust based on the FRMSPC field. In the other problems, this field value will define the width of the panel at the local stage.

   To analyze with the default settings, leave the value as zero. The skin sheet's thickness will be obtained from the master element.

5. LENGTH: This field represents the length of the panel's skin sheet.

   To analyze with the user defined settings, enter a value greater than zero. In the case of discrete source damage problems, this field value will define the length of the panel at the intermediate stage. If the total distance between the two end stringers is greater than the entered value, the length will automatically adjust based on the STRSPC field. In the other problems, this field value will define the width of the panel at the local stage.

To analyze with the default settings, leave the value as zero. The skin sheet's length will be obtained from the master element.

6. `RADIUS`: This field represents the radius of the curved panel. This field is relevant to discrete source damage problems only.

   To analyze with the user defined settings, enter a value greater than zero. The panel becomes curved, and this field value will define the radius of the panel at the intermediate stage.

   To analyze with the default settings, leave the value as zero. The panel becomes flat.

7. `BARSTR`: This field represents the bar geometrical property ID of the stringers of the panel. This field is relevant to discrete source damage problems only.

   To analyze with the user defined settings, enter a value greater than zero. The selected PBAR data entry will define the bar geometrical properties of the beam elements of the stringers at the intermediate stage.

   To analyze with the default settings, leave the value as zero. This will assume that the panel has no stringers.

8. `BARFRM`: This field represents the bar geometrical property ID of the frames of the panel. This field is relevant to discrete source damage problems only.

   To analyze with the user defined settings, enter a value greater than zero. The selected PBAR data entry value will define the bar geometrical properties of the beam elements of the frames at the intermediate stage.

   To analyze with the default settings, leave the value as zero. This will assume that the panel has no frames.

9. `STRPSCH`: This field represents the rivet pitch along the stringers, i.e. the distance between two rivets along the stringers. This field is relevant to discrete source damage problems only.

   To analyze with the user defined settings, enter a value greater than zero. To connect the rivets to the stringers and the skin sheet, enter a value which is less than the value of the FRMSPC field, the frame spacing. To have the stringers not connected to the skin, enter a value which is greater than the value of the FRMSPC field. This allows the stringer to be indirectly connected to the skin via the frame and stringer intersection.

   Note, the size of the finite element model at the intermediate stage depends on the rivet spacing.

10. `STRSPC`: This field represents the stringer spacing of the panel, i.e., the distance between two stringers. This field is relevant to discrete source damage problems only.

    To analyze with the user defined settings, enter a value greater than zero. This field value will define the stringer spacing.

    To analyze with the default settings, leave the value as zero. This will assume that the panel has no stringers.

This field also affects the existence of rivet connections between the frames and the skin. If there are rivets on the frames, frame rivet pitch, FRMPCH, must be less than STRSPC.

11. FRMPCH: This field represents the rivet pitch along the frames of the panel, i.e., the distance between any two rivets on the frames. This field is relevant to discrete source damage problems only.

    To analyze with the user defined settings, enter a value greater than zero. To connect the rivets to the frames and the skin, enter a value which is less than the value of the STRSPC field, the stringer spacing. To have the frames not connected to the skin, enter a value which is greater than the value of the STRSPC field. This allows the frame to be indirectly connected to the skin via the frame and stringer intersection.

    Note, the size of the finite element model at the intermediate stage depends on the rivet spacing.

12. FRMSPC: This field represents the frame spacing of the panel, i.e., the distance between two stringers. This field is relevant to discrete source damage problems only.

    To analyze with the user defined settings, enter a value greater than zero. This field value will define the frame spacing.

    To analyze with the default settings, leave the value as zero. This will assume that the panel has no frames.

    This field also affects the existence of the rivet connections between the frames and the skin. If there are rivets on the stringers, stringer rivet pitch, STRPCH, must be less than FRMSPC.

Entity: DTCNTL

Entity Type: Relation

Description: Describes the control parameters required for Damage Tolerance Analysis

Relation Attributes:

NAME	TYPE	DESCRIPTION
TYPE	C(8)	Damage Type
DMG	KI>0	Damage ID
PNLELM	I>0	PNLELM ID
ANGLE	R>0	The angle between the crack coorindate system and the element stress coordinate system.
PNLSTF	I>=0	PNLSTF ID
CFTG	I>=0	CFTG ID
CNTL	I>=0	Damage dependent control card ID
METHOD	C(8)	Analysis method

Created By: Module IFP

Remarks:

1. The damage ID DMG must be unique among DDSD, DBKDEL, DHLSF, DSF, DTWC, DHLTWC, DCVC, and DHLCVC.

2. ANGLE is used to determine the orientation of the stiffeners or the cracks.

3. METHOD can be one of the following keywords INF, BETA or FEAM. Available options for different type of damages are as follows.

	DTWC	DHLTWC	DCVC	DHLCVC	DSF	DHLSF	DDSD	DBKDEL
INF	√	√						
BETA	√	√	√	√	√	√		
FEAM	√	√	√	√	√	√	√	√

INF: use the analytical solution for the crack in the infinite sheet. BETA: use pre-calculated beta factors FEAM: use Finite Element Alternating Method

4. SIF must be uniquely defined for each crack tip if the user choses to calculate the SIF using beta factors.

Entity: CFTG

Entity Type: Relation

Description: Define the fatigue damage module

Relation Attributes:

NAME	TYPE	DESCRIPTION
CFTG	I>0	Control ID
FRACMT	I>0	Fatigue material properties ID
FLTSEQ	I>0	Flight sequence ID
REPEAT	R>0	Scale factor
VSTEP	R>0	SIF update frequency (in terms of the amount of crack growth)
DN	R>0	Fatigue crack growth step (in terms of number of cycles)

Created By: Module IFP

Remarks:

1. REPEAT: number of times that design usage (LIFE) should be repeated
2. VSTEP: percentage of crack growth before the SIF is updated

Entity: CTWC

Entity Type: Relation

Description: Defines the control parameters for the analysis of a through wall crack

Relation Attributes:

NAME	TYPE	DESCRIPTION
CTWC	I>0	Control ID
CASEID	I>0	ASTROS CASEID
PRINT	C(8)	Flag for result printing

Created By: Module IFP

Remarks:

1. None

Entity: CHLTWC

Entity Type: Relation

Description: Defines the control parameters for the analysis of cracks emanating from a rivet hole

Relation Attributes:

NAME	TYPE	DESCRIPTION
CHLTWC	I>0	Control ID
CASEID	I>0	ASTROS CASEID
PRINT	C(8)	Flag for result printing

Created By: Module IFP

Remarks:

1. None

Entity: CSF

Entity Type: Relation

Description: Defines the control parameters for the analysis of a surface flaw

Relation Attributes:

NAME	TYPE	DESCRIPTION
CSF	I>0	Control ID
CASEID	I>0	ASTROS CASEID
PRINT	C(8)	Flag for result printing

Created By: Module IFP

Remarks:

1. None

Entity: CHLSF

Entity Type: Relation

Description: Defines the control parameters for the analysis of corner cracks emanating from a rivet hole

Relation Attributes:

NAME	TYPE	DESCRIPTION
CHLSF	I>0	Control ID
CASEID	I>0	ASTROS CASEID
PRINT	C(8)	Flag for result printing

Created By: Module IFP

Remarks:

1. None

Entity: CCVC

Entity Type: Relation

Description: Defines the control parameters for the analysis of a curved crack

Relation Attributes:

NAME	TYPE	DESCRIPTION
CCVC	I>0	Control ID
CASEID	I>0	ASTROS CASEID
PRINT	C(8)	Flag for result printing

Created By: Module IFP

Remarks:

1. None

Entity: CHLCVC

Entity Type: Relation

Description: Defines the control parameters for the analysis of curved cracks emanating from a rivet hole

Relation Attributes:

NAME	TYPE	DESCRIPTION
CHLCVC	I>0	Control ID
CASEID	I>0	ASTROS CASEID
PRINT	C(8)	Flag for result printing

Created By: Module IFP

Remarks:

1. None

Entity: CDSD

Entity Type: Relation

Description: This data entry describes the control data required for the discrete source damage problem. It specifies the following information for the discrete source damage problem: the fracture properties; the load case; and the variation of the half crack length. Single or multiple steps of the intermediate-local analyses with different crack lengths can be performed to calculate the beta factor. The range of steps is specified also. For multiple step intermediate-local analyses, a stress intensity factor is calculated for a crack that varies in length for each step. The beta factor is calculated from the stress intensity factor result for each step.

Relation Attributes:

NAME	TYPE	DESCRIPTION
CNTL	I>0	This field represents the data entry ID of this data entry
FRACMT	I>0	Fracture property ID of the skin sheet of the panel
CASEID	I>0	Loading case ID
MINCRK	R>0	Minimum half crack length
MAXCRK	R>0	Maximum half crack length
NSTEP	I>=0	Number of step between minimum and maximum half crack length

Created By: `Module IFP`

Remarks:

1. FRACMT: This field represents the fracture property ID of the panel's skin. The fracture properties are then used for the fracture mechanics calculation of the local model.

2. MINCRK: This field represents the minimum half crack length of the discrete source damage problem.

   To analyze with the user defined settings, enter a value greater than zero. This value will be used as the minimum half crack length.

3. MAXCRK: This field represents the maximum half crack length of the discrete source damage problem.

   To analyze with the user defined settings, enter a value greater than zero. This value will be used as the maximum half crack length.

4. NSTEP: This field represents the number of steps of the discrete source damage problem.

To analyze with the user defined settings, enter a value greater than zero. This value will define the number of steps required for the analysis.

To analyze with the default settings, leave the value as zero. The program will then define the number of steps required for the analysis. If the value of MAXCRK equals MINCRK, then a one step analysis is set. If they are not equal, a two step analysis is set.

Entity: CBKDEL

Entity Type: Relation

Description: This data entry describes control data required for the buckling and delamination problem. It specifies the following information for the buckling and delamination problem: the load case.

Relation Attributes:

NAME	TYPE	DESCRIPTION
CNTL	I>0	This field represents the data entry ID of this data entry
CASEID	I>0	Loading case ID

Created By: Module IFP

Remarks:

1. None

Entity: SIF

Entity Type: Relation

Description: Defines the beta factors for the stress intensity factors at one crack tip or a point on the crack front

Relation Attributes:

NAME	TYPE	DESCRIPTION
DMG	I>0	Crack ID
ID	I>0	Tip/Point ID for the specific crack
Kn	R	SIF for mode I, II, III (n=1,2,3)
BETAn	R	beta factors (n=1,2,3)

Created By: Module IFP or TCL

Remarks:

1. Tip/Point ID for a given type of crack (for example, DTWC) are specified in the corresponding input card for that crack.
2. The definition of the beta factors are defined in the corresponding input cards for the cracks.

Entity: FRACMT

Entity Type: Relation

Description: Defines the fracture material properites

Relation Attributes:

NAME	TYPE	DESCRIPTION
FRACMT	KI>0	Fracture material property ID
KIC	R>=0	Critical Stress Intensity Factor
KTH	R>=0	Stress Intensity Factor Threshold
COEF	R>=0	Coefficient c
EXPM	R>=0	Coefficient m
EXPN	R>=0	Coefficient n
EXPP	R>=0	Coefficient p
EXPQ	R>=0	Coefficient q

Created By: `Module IFP`

Remarks:

1. c, m, n, p and q are the coefficients in the following generic fatigue crack growth rate equation.
$$\frac{da}{dn} = \frac{c(\Delta K)^m(1-R)^p(\Delta K - K_{th})^q}{[(1-R)K_{Ic} - \Delta K]^n}$$
2. This generic fatigue crack growth rate equation becomes Paris equation when $n = p = q = 0$.
3. This generic fatigue crack growth rate equation becomes Forman equation when $n = 1$ and $p = q = 0$.

Entity: GELP

Entity Type: Relation

Description: This data entry describes the analysis results of the buckling and delamination problem. It specifies the following information for the buckling and delamination problem: the buckling load.

Relation Attributes:

NAME	TYPE	DESCRIPTION
GELP	I>0	This field represents the data entry ID of this data entry
BKLOAD	R	Buckling load factor

Remarks:

1. None

Entity: PDTWC

Entity Type: Relation

Description: Fatigue crack growth prediction for DTWC

Relation Attributes:

NAME	TYPE	DESCRIPTION
DMG	I>0	The crack ID DTWC
A	R>0	Half length of the crack
CYCLE	R>0	No. of Cycle to reach the current crack length

Created By: Module TCL

Remarks:

1. None

Entity: PDHLTWC

Entity Type: Relation

Description: Fatigue crack growth prediction for DHLTWC

Relation Attributes:

NAME	TYPE	DESCRIPTION
DMG	I>0	The crack ID DHLTWC
A1	R>0	Crack length
A2	R>0	Crack length
CYCLE	R>0	No. of Cycle to reach the current crack length

Created By: Module TCL

Remarks:

1. None

Entity: PDSF

Entity Type: Relation

Description: Fatigue crack growth prediction for DSF

Relation Attributes:

NAME	TYPE	DESCRIPTION
DMG	I>0	The crack ID DSF
A	R>0	Half length of the surface flaw
B	R>0	Depth of the surface flaw
CYCLE	R>0	No. of Cycle to reach the current crack size

Created By: Module TCL

Remarks:

1. None

Entity: PDHLSF

Entity Type: Relation

Description: Fatigue crack growth prediction for DHLSF

Relation Attributes:

NAME	TYPE	DESCRIPTION
DMG	I>0	The crack ID DHLSF
A	R>0	Length of the corner crack
B	R>0	Depth of the corner crack
CYCLE	R>0	No. of Cycle to reach the current crack length

Created By: Module TCL

Remarks:

1. None